MEMORANDUM

December 16, 1946

To: All Fieldmen
Applications & Loans Division

From: Arthur W. Gerth, Chief
Applications and Loans Division

Subject: Attached article "Basic Concepts of Loads"

The attached article contains a general discussion of the types of loads, their characteristics and applications as are commonly encountered in our everyday work. Reference is made in the article to such terms as demand, load factor, diversity factor and other terminology with which all of our fieldmen should be familiar even though a number of you are not engineers.

With increased emphasis and activity being centered on our power use program, system load studies, etc., the discussions contained in this article should be of special interest to each of you.

Arthur W. Gerth

BASIC CONCEPTS OF LOADS

A. LOADS AND THEIR CHARACTERISTICS

A study of loads and their characteristics involves not only the different types of apparatus used and the grouping of such apparatus to form the load of an individual consumer, but also the grouping of such loads into still larger diversified groups. For example, the electric range should be studied as a piece of apparatus which is quite commonly used. Its characteristics as an individual load should be understood. Further, its effect on the total load of a consumer using it as a part of his electrical equipment must be considered. Then, farm load as a class must be studied, that is, the load imposed on a system by an area distinctly rural in character and including consumers using electric ranges, refrigerators, etc. Finally, attention must be given to composite loads drawn by larger areas, consisting of certain proportions of industrial power load, irrigation load, non-farm, and recreational load as well as farm load, and perhaps of other characteristically different types. Such a load would be represented by the total load on a substation carrying both farm and power loads, irrigation, commercial, etc.

Before proceeding with the study of particular types of loads, it is essential that an understanding be had of what are the important characteristics of a load and how, in general, they affect the design of the system. A few simple definitions are in order at this point.

Demand: The size of any load, or its demand, is the maximum load, expressed in kilowatts (KW) at a certain power factor, or in kilovolt-amperes (KVA), which is drawn from the source of supply at the receiving or delivery point. The determination of the demand of any load or group of loads is of the highest importance since it is the demand which governs the size of conductors, transformers, etc.

Demand Factor: The distinction between demand and connected load on any service should be noted. Connected load is the total of the rated capacities of all electric appliances, lamps, motors, etc., which are connected to the wiring of that service. The actual demand in nearly all cases is considerably less than the connected load due to the fact that different pieces of apparatus are used at different times. The ratio of maximum power demand to the total connected load is called the demand factor. For example, ten 5-hp. motors on one service may have an actual demand of only 25 hp. instead of 50 hp. In this case, the demand factor equals 25/50 or 50 percent. Demand factor is usually applied to the demand of an individual consumer and should not be confused with diversity factor.

Diversity Factor: The diversity factor is the ratio of the sum of maximum power demands of the component parts of any load to the maximum demand of the load as a whole measured at the point of supply. For example, a transformer may serve five consumers, each with a maximum demand of 4 KVA. Due to the

Diversity Factor (Continued)
fact that the maximum demands of all five do not come at the same time, the actual demand on the transformer may be only 10 KVA instead of 20 KVA. In this case the diversity factor equals 20/10, or 2. (It should be noted that demand factor is defined in such a way that it is always less than 1; diversity factor in such a way that it is always greater than 1, that is, the form of one is the reciprocal of the other).

Such diversity is found between consumers, between transformers, between feeders, between substations, etc. It can be used to marked advantage in reducing the required capacity of such parts of the system from that which would be necessary if design were based on connected load or on the sum of component demands only.

Load Factor: Load factor is the ratio of the average power for a certain stipulated period of time, such as a day, a month, or a year, to the maximum power or demand for a short interval of time (say 15-minute integrated demand) during the same period. In referring to the load factor in any particular case, both the interval of time for the maximum demand and also the period of time for which the average power is taken should be specified. Load factor is an index of the efficiency with which the system under consideration is utilized, 100 percent load factor or 24-hour per day operation at peak load being the maximum possible.

B. APPLICATION OF LOAD CHARACTERISTICS TO FARM USAGE

Farm Lighting: Lamps form a part of nearly all consumers' loads since artificial illumination, for a part of the day at least, is necessary. Lamp load of itself shows no diversity between individual units (lamps) when in operation since the load of each lamp is essentially constant while it is in use. There is considerable diversity in use, however, especially in residence lighting where only a comparatively small proportion of the total number of lamps connected is ordinarily used at any one time.

The load factor of lamp load may be almost any amount from a very small value for lamps which are used occasionally up to 100 percent where they are used continuously. For the ordinary residence, the lamp load factor is rather low (probably not over 10 to 15 percent on a yearly basis) since illumination is required for only a comparatively small portion of the day. In stores and offices it will run somewhat higher as a rule due to the greater daytime use. Street lighting lamp load has usually a fairly high load factor especially where all night lighting is practiced (of the order of 50 percent).

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Farm Lighting (continued)

Figure 1 (below) shows a typical residence-lighting load curve for 1,000 consumers:

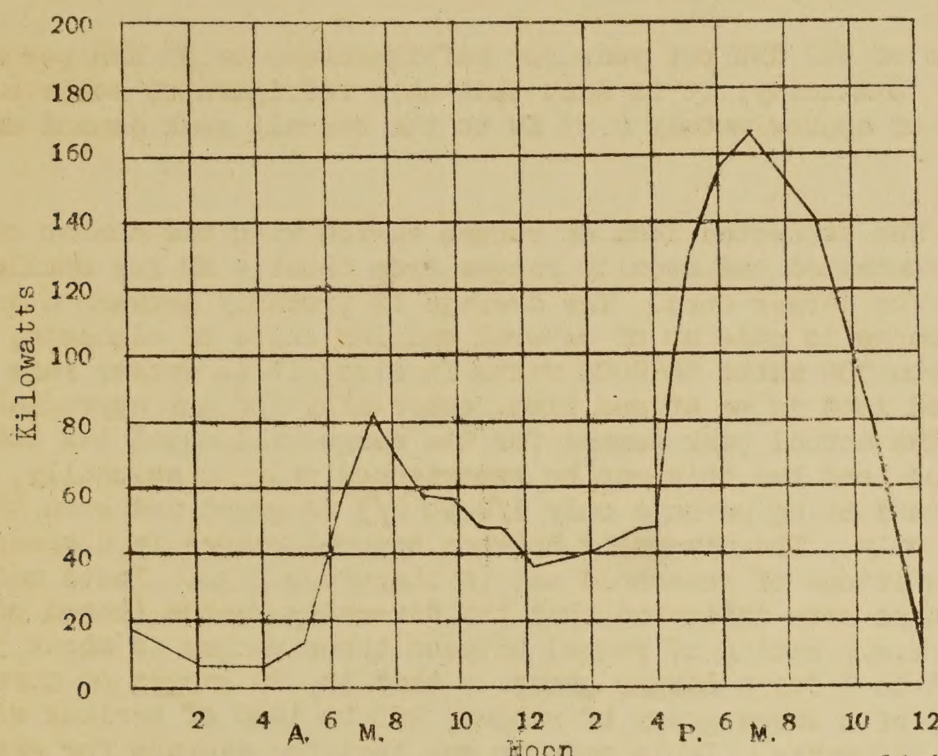

Figure 1. Typical daily load - 1,000 Consumers, lighting.

It is noted from Figure 1 that the maximum demand created by lighting and minor other uses for 1000 residential consumers is approximately 165 KW. Since the curve in Figure 1 takes into consideration the diversity between consumers, the average demand contributed by each consumer to the actual peak lighting demand is .165 KW.

Due to earlier rising time and other characteristic farm practices, it is felt that farm residential lighting demands as well as the load factor of this type of load may slightly exceed the above figures on the average farm. For this reason, the average demand per consumer at peak load for farm residence lighting has been estimated at 0.2 KW, or 200 KW per 1000 farm consumers. Applying a 17 percent lighting load factor (annual) to this demand, we have:

> 8760 (hours in 1 year) x 200 x 17% = 297,840 KWH, or an average consumption of approximately 297 KWH per farm consumer per year for lighting and minor other uses.

Refrigerators: Refrigeration equipment is usually operated automatically (thermostatically) and is as likely to be operated at the time of peak load as at any other time, thus adding directly to the peak. Since they are operated intermittently on a fairly constant mechanical load, their load factor is comparatively high and the diversity comparatively low.

From load curves similar to Figure 1, it has been found that 1000 refrigerators operating on a system may contribute approximately 68 KW toward the overall system peak even though the connected load of 1000 refrigerators would be much greater. On the basis of a 70 percent refrigeration load factor (annual) as

applied to the peak demand of 68 KW, the annual KWH consumption of 1000 refrigerators would be:

8760 X 68 X .70, or 416,976 KWH.

This is an average of 417 KWH per year per refrigerator, or 35 KWH per month per refrigerator. Similarly, it is seen that each refrigerator contributes an average demand of approximately 0.07 KW to the overall peak demand of the system.

Electric Ranges: The connected load of ranges varies with the number of heating elements contained and usually ranges from about 4 KW for smaller ones to 7 or 8 KW for larger ones. The average is probably between 6 and 7 KW. Since the range is made up of several smaller units or elements, usually ranging from 500 watts to 2000 watts in size, it is rather rare that the whole connected load is on at one time, especially for any appreciable length of time. The actual peak demand for the range will equal its total rating or connected load but this may be experienced only occasionally, the ordinary daily demand being perhaps only 1/2 to 2/3 as great and even that for short periods only. The diversity between several ranges in a group, under ordinary conditions of household use is therefore high. Tests made in various localities have indicated that the diversity factor (based on actual peak load, i.e., rating of range) between three ranges is about 3, and increases to 5 to 7 for a larger group -- that is, 20 ranges or more. The average demand of a large group of ranges, 200 to 1000 of various sizes has been given as 728 watts. It is safe to say that the average for even much smaller groups (over 20 ranges) will not be more than 1 KW each. The range peak for a few ranges may be less than the lighting peak and hence will add only a comparatively much smaller amount to that peak. Where the percent saturation of ranges is large in comparison to the number of lighting consumers served, the range load may well predominate, since few groups of farm consumers have an average lighting demand of anything like 1 KW per farm.

Load factor for a single range is very low, but for a group of ranges is much better, being somewhat of the same order as load factor for lighting load. An annual load factor of 4 percent for a single range based on its peak demand and 23.2 percent for a large group (200 or over) based on the group demand has been found by test. Applying a load factor of 23.2 percent to the peak demand of 670 KW (demand of 1000 ranges as found from tests) we can calculate the KWH used by 1000 ranges over the period of one year, as follows:

8760 X 670 X 23.2% = 1,361,654 KWH.

From this it is seen that the average consumption per year per range would be 1362 KWH or 113 KWH per month per range. These calculations compare favorably with accepted estimates of 100-120 KWH per month per range, or 1200 to 1440 KWH per year.

On average REA projects where the percent saturation of ranges connected will be large compared to total number of consumers, the average demand per range contributing to the overall peak demand of the system may be taken as approximately 0.75 KW; on smaller projects where the estimated number of ranges connected will be less than 200, it may be well to use an estimated average demand per range of 1.0 KW as contributing to the overall peak system demand.

Water Heaters: The water heater is likely to be turned on at the time of the peak lighting load, especially if it is automatically operated, and hence may add to the peak demand of the consumer and of the distribution system.

Operations Memorandum 28-2 dated September 30, 1945, makes the following comment on electric water heating with respect to REA systems:

> "A careful consideration of this problem convinces us that at present it will not be necessary to require the installation of time switches to control these heaters on an off-peak basis. However, as peak-load conditions develop on the individual systems, this will become a matter of concern, and at that time it will become necessary to install time switches.
>
> "Water heaters for use in controlled 'off-peak' service shall be of the double element type, 230-240 volt. Neither the upper nor lower element shall exceed 2500-watt capacity. The upper element shall be located near the top of the tank so that it will heat the top fourth of the water and so connected that it can operate at any time except when the lower element is in operation. This is accomplished by using a three-point thermostat to control the upper element and by not opening this circuit with the time switch. Lower element shall be equipped with a standard thermostat, shall operate only during 'off-peak' periods and can be controlled by a time switch. Time switches to control the lower element shall be operated by a 230-240 volt synchronous motor with an auxiliary electrically wound clock mechanism to provide a fifteen-hour carryover period in case of service interruption."

From the above we can assume that time switches will be used in the future on systems where water heaters develop into more general use and where the percent saturation of consumers having water heaters will be substantial as compared with the total number of consumers served.

Since, for purposes of estimating the demand of water heating load, we are primarily concerned with that portion of the load that will contribute to the overall system peak, we may automatically eliminate the 50 percent of the connected load which will be controlled by time switches. The actual peak demand of a single water heater will therefore equal 1/2 its total rating or connected load. The diversity between several water heaters in a group under ordinary conditions of household and farm use would be comparatively low. It is assumed that since the uncontrolled element of a water heater would be automatically (thermostatically) operated during the system peak, the diversity factor for a large group of water heaters - that is, 20 or more - would be comparable to that of a similar number of refrigerators, or something like 3.4 to 4. The average demand of a large group of water heaters, 200 to 1000 of the type recommended for consumers on REA systems, would be approximately 735 watts per water heater using the assumed diversity factor of 3.4.

It should be emphasized that the above discussion of average demand as applied to a group of water heaters refers to that portion of the water heating load which may directly contribute to the peak demand of the system, even when time clocks are used with the particular type of water heater discussed.

Small Heating Appliances: Small heating appliances are a large contributing factor to the comfort of the modern household and form a part of nearly all farm and residence loads. They include flat irons, toasters, percolators, heating pads, waffle irons, heaters, curling irons, and an infinite number of other similar devices. As a rule, they are probably more effective in increasing the consumption of current, that is, improving the load factor, than in adding to the load demand except in the case of the larger units. Most of them are used more or less intermittently and at times of the day other than when the lighting peak is on, hence their load factor (of each unit individually) is usually extremely low and the diversity between various units very high. On any one service, the actual peak demand may be due to one or more of such appliances - a toaster or flatiron drawing 750 watts, if added to a certain amount of lighting, may well exceed the peak due to lighting alone. The high diversity and time of use, however, will cause the effect on the total demand of a group of such loads to be comparatively small.

Small Motors: Fractional horsepower motors are the motive power for vacuum cleaners, washing machines, ventilating fans, electric refrigerators, electrically-operated oil burners (furnaces), and similar equipment.

A very high diversity factor and low-load factor is obtained with such appliances as vacuum cleaners, washing machines, etc., whose use is only occasional and for comparatively short periods. Rarely do they add any appreciable amount to the peak load, their effect being chiefly an increase in consumption and hence in load factor. With refrigerators and oil burners, however, the case is somewhat different as was seen in the previous discussion on refrigerators. Oil burners compare favorably with refrigerators, except for their seasonal use, and will not be discussed here.

Commercial Load (Stores, Small Manufacturing Shops, Theaters, Markets, Etc.): Commercial load is characteristically a combined light and power load with the lighting usually predominating but not always. The proportion in which they combine depends entirely on conditions -- for example, the ordinary small store will have a few motors such as coffee or meat grinders, ventilating fans, refrigerating machines, etc., but these run intermittently and may take a very small load compared with the lighting which may include a fairly large demand for window lighting, electric signs, display lighting, etc. The diversity between individual demands for power load only is likely to be high since the power load is usually diversified as to use. For the lighting load, however, a low diversity will usually exist since with such lighting, nearly all the connected load is likely to be used at the same time. There is not likely to be much diversity between power and lighting peak for such loads.

Power Load (Rural Industries): There is no definite dividing line between what may be called power loads and the commercial loads discussed above. Power loads are usually thought of as being predominately power with only a comparatively small amount of lighting.

Power loads are governed by differences in type of manufacture, method of operation, plant design, efficiency of management, and numerous other factors so that there is quite a wide variation in such elements as power factor, load

Power Load (Rural Industries): (continued)
factor, diversity, etc., not only between different industries but also between different individuals in the same industry. Such figures as can be given in this regard must be considered as only very general and not applicable with any degree of accuracy to any particular case without further investigation. With this reservation, some characteristic demand factors for various industries are listed below:

Type of Manufacturing	Demand Factor
Boat	0.51
Cement and Asbestos products	0.63
Chemical	0.50
Cleaners and dyers	0.68
Clothing	0.45
Creamery	0.77
Excelsior	0.90
Grain elevator	0.69
Ice	0.92
Knitting mills	0.86
Laundry	0.82
Lime products	0.65
Lumber	0.64
Meat packing	0.79
Paper	0.75
Paper products	0.47
Pottery	0.60
Tobacco	0.61
Woodworking	0.55

If we wish to get more accurate demand factors, the following must be considered:

1. Total connected load - as the total connected load increases the demand factor decreases.
2. Size of individual motors - the larger the motors compared with total load, the higher the demand factor.
3. Grouping of motors, i.e., whether consumer has all large or all small motors, or a number of each.
4. Ratio of size of large motors to small motors.

Irrigation Loads: Irrigation loads may easily predominate over all other composite loads of a system in areas where the practice of irrigation is extensive. Examples of such cases may be found in arid areas of Colorado and New Mexico. Though seasonal in character, ranging from 4 to 8 months or more, depending on the growing season, the irrigation pump load is as likely to occur at the time of peak load as at any other time, thus adding directly to the peak. Since the pumps are operated seasonally, and even then intermittently to a great extent, their load factor is comparatively low.

The diversity between irrigation consumers will vary, however, a diversity factor of 1.5 for less than 100 pumps, and 2.0 for 100 pumps or more, has been used.

On the following page is a chart which has been prepared for use in calculating KWH consumption for irrigation loads under various conditions. In using the chart the following information would first have to be obtained in the area under study:

(1) Crops grown.
(2) Acreage devoted to each crop (average).
(3) Feet of water applied to each crop per season.
(4) Total pumping head in feet. If pumping against a pressure, such as distributing water through a sprinkling system, the pounds per square inch (pressure) should be multiplied by 2.31 to obtain feet of head, and this result added to the lift in feet to obtain the total head in feet.
(5) Capacity of pump or well in gallons per minute.

Example: The above information is obtained and water requirements determined in the following manner for an average farm:

Crops Grown	Acres		Water Applied Per Season (Feet)		Acre Feet Applied
Alfalfa	5	X	3	=	15
Sugar Beets	15	X	1-1/2	=	22-1/2
Corn	10	X	1-1/2	=	15
Barley	5	X	1-1/2	=	7-1/2
Potatoes	5	X	1-1/2	=	7-1/2
			Total acre-feet of water applied		67-1/2

The irrigator (or county agent) states that a well, or wells in the general area, will produce about 950 gallons per minute with a 55-foot lift. On looking at the chart, we find that the chart is not made up for 55 feet; however, if the output of a pump is increased, the depth to water will usually increase, and when the capacity is decreased the lift will be less. From the chart we find that at a 50-foot head 910 gallons per minute can be pumped with a 15 h.p. motor with a 13.2 KW demand, and at 60-foot head 1010 gallons per minute can be pumped with a 20 h.p. motor, creating a 17.6 KW demand. The smaller motor will create less KW demand on REA lines and by pumping longer hours the same quantity of water may be pumped as with the larger motor. Therefore, we will select the 15 h.p. installation which uses 13.2 KWH per hour of operation. From this we can calculate the KWH consumption required to pump the 67-1/2 acre-feet of water desired for irrigation as follows:

Hours required to pump 1 acre-foot: $\dfrac{325{,}850 \text{ Gal. per acre foot}}{\text{Gal. per min. X 60 min.}} = \dfrac{5430}{\text{G.P.M.}}$

Since the installation chosen will pump 910 gallons per minute,

Hours required to pump 1 acre-foot: $\dfrac{5430}{910} = 5.97$

Time required to pump 67-1/2 acre feet: 67.5 x 5.97 = 403 hours

Electrical consumption from chart was 13.2 KWH per hour of operation. Therefore, KWH required to pump 67-1/2 acre-feet: 403 x 13.2 = 5319.

CAPACITY PUMPED - GALLONS PER MINUTE
BASED ON 65 PER CENT OVERALL (WIRE TO WATER) EFFICIENCY

Horse Power Motors	Feet of Head 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	KWH per hour of operation & KW demand of motor based on 85% motor efficiency
5	1520	760	510	380	300	250	220	190	170	150	140	130	120	110	100	95	90	85	80	4.4
7½	2280	1140	760	570	460	380	330	280	250	230	210	190	180	160	150	140	135	125	120	6.6
10	3040	1520	1000	760	610	510	430	380	340	300	280	250	230	220	200	190	180	170	160	8.8
15	4560	2280	1520	1140	910	760	650	570	510	460	410	380	350	330	300	280	270	250	240	13.2
20	6080	3040	2010	1520	1220	1010	870	760	680	610	550	510	470	430	400	380	360	340	320	17.6
25	7610	3800	2540	1900	1520	1270	1090	950	850	760	690	630	530	540	510	480	450	420	400	22.0
30	9130	4560	3020	2280	1830	1520	1310	1140	1020	910	830	760	700	650	610	570	540	510	480	26.4
40	12200	6100	4060	3050	2440.	2020	1740	1520	1360	1220	1110	1020	940	870	810	760	720	680	640	35.2
50	15200	7600	5070	3800	3040	2530	2170	1900	1690	1520	1380	1270	1170	1080	1010	950	890	840	800	43.9

This chart may be used for approximation and should not be used for actual installation.

Head equals feet of lift to ground surface plus additional feet to point where water is discharged.

1 Acre Foot = 325,850 Gallons
450 gallons per minute = 1 acre inch per hour - approx.
1 pound per square inch = 2.31 foot head of water

From the above example it is seen that the installation chosen would create a 13.2 KW demand and that 5319 KWH would be consumed per season in supplying the water required for irrigation.

The chart may be equally useful in calculating KWH consumption where water is pumped from rivers and streams into gravity ditches, or into sprinkler systems.

Farm Equipment: In addition to the typical home equipment items and appliances, some of which have already been discussed, the modern farm will be equipped with various items of farm equipment, including brooders, cream separators, dairy water heaters, milk coolers, ensilage cutters, milking machines, tool grinders, water pumps, and cut-off saws (wood fuel) to mention a few. A great deal of this equipment will be operated during daylight hours or at times other than that at which the system peak occurs. Rarely will they add any appreciable amount to the peak load of a consumer or system, their effect being chiefly an increase in consumption and hence in load factor. A very high diversity factor and low load factor (individual units) is obtained with such equipment.

Admittedly, such items of equipment as barn ventilators, chick and pig brooders, dairy water heaters, milk coolers, poultry house lighting, barn lighting, and water pumps would create some demand responsibility on a system. It would not seem desirable nor practical to treat each of the above items separately and attempt to determine the demand responsibility of each appliance. Rather, it is felt that such items may be treated as a group and an estimate made of the demand responsibility for this type of load based upon the conditions found in the field. For instance, on projects where the estimates of present saturation in the use of farm equipment are found to be substantial (50% or more) the field man may elect to include in his estimates of average demand per farm consumer an arbitrary figure of 0.2 KW per consumer to cover the demand responsibility attributed to the use of farm equipment generally; on other projects with lower estimates of percent saturation and where less favorable conditions are found, he may elect a smaller figure of say 0.15 KW per farm consumer.

C. METHODS OF ESTIMATING APPLIED TO FARM LOADS

Now let us consider the application of methods of estimating the composite load of a group of consumers such as would be found on an REA project. The discussion here will be confined to farm consumers though the methods used may be equally useful in estimating loads of non-farm, commercial, or recreational usages.

For purposes of demonstration, we will assume that the study has progressed to the point where the estimates of percent saturation of the various home and farm appliances have been determined for a given year (say 1952) and tabulated in column form as in Table 1 (attached). Turning to Table 1, we will proceed to determine in Column (2) the Total Average Yearly Consumption (KWH) per 100 consumers based on accepted standards of KWH usage per unit appliance. Likewise, in Column (3), the demand responsibility (KW) per unit appliance is assigned to those loads whose existence on the system is known to contribute substantially to the system peak. On those items of equipment where the demand responsibility would be small, such items are grouped into "Miscellaneous" and accounted for by allowing 0.15 KW for domestic and 0.15 KW for farm equipment each per 100 consumers on the system.

TABLE 1 (Continued)

GROUP LOAD ESTIMATES PER 100 CONSUMERS - 1952

Type of Use	Col. (1) No. Per 100 Consumers	Col. (2) Av. Yearly KWH Per 100 Cons.	Col. (3) Demand Responsibility Per 100 Consumers (KW)
Farm Equipment:			
Chick Brooders	30	10,800	(x)
Cream Separators	30	1,050	(x)
Dairy Water	25	37,500	(x)
Milking Machines	30	14,400	(x)
Milk Coolers	20	18,000	(x)
Ensilage Cutters	5	250	
Grain Elevators	5	500	
Feed Mixer	5	60	
Bench Saws	5	60	
Welder	10	1,000	
Tool Grinders	10	250	
Drill Presses	10	120	
Air Compressors	5	175	
Lights - Barn	50	1,200	(x)
Poultry	25	875	(x)
Dairy Barn	30	1,800	(x)
Milk House	30	1,050	(x)
(x) Miscellaneous	100	-	(@ 0.15 KW) 15
Total		89,090	15

NOTE: Items designated (x) in Column 3 are grouped into "miscellaneous" and accounted for by allowing 0.15 KW each per 100 consumers. Items for which no demand is shown are presumed to have little or no effect on overall system peak demand.